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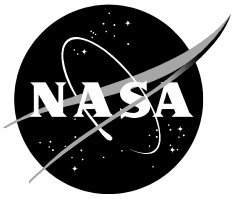

TESS Data Release Notes:
Sector 39, DR56

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August 4, 2021

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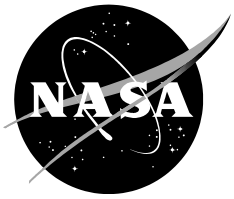

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Acknowledgements

These Data Release Notes provide information on the processing and export of data from the Transiting Exoplanet Survey Satellite (TESS). The data products included in this data release are full frame images (FFIs), target pixel files, light curve files, collateral pixel files, cotrending basis vectors (CBVs), and Data Validation (DV) reports, time series, and associated xml files.

These data products were generated by the TESS Science Processing Operations Center (SPOC, Jenkins et al., 2016) at NASA Ames Research Center from data collected by the TESS instrument, which is managed by the TESS Payload Operations Center (POC) at Massachusetts Institute of Technology (MIT). The format and content of these data products are documented in the Science Data Products Description Document (SDPDD)[1]. The SPOC science algorithms are based heavily on those of the Kepler Mission science pipeline, and are described in the Kepler Data Processing Handbook (Jenkins, 2020).[2] The Data Validation algorithms are documented in Twicken et al. (2018) and Li et al. (2019). The TESS Instrument Handbook (Vanderspek et al., 2018) contains more information about the TESS instrument design, detector layout, data properties, and mission operations.

The TESS Mission is funded by NASA's Science Mission Directorate.

This report is available in electronic form at
https://archive.stsci.edu/tess/

[1] https://archive.stsci.edu/missions/tess/doc/EXP-TESS-ARC-ICD-TM-0014-Rev-F.pdf
[2] https://archive.stsci.edu/kepler/manuals/KSCI-19081-003-KDPH.pdf

1 Observations

TESS Sector 39 observations include physical orbits 85 and 86 of the spacecraft around the Earth. Data collection was paused for 1.00 days between the orbits to download data. In total, there are 26.95 days of science data collected in Sector 39.

Table 1: Sector 39 Observation times

	UTC	TJD[a]	Cadence #
Orbit 85 start	2021-05-27 06:21:03	2361.76612	816704
Orbit 85 end	2021-06-09 08:31:03	2374.85639	826129
Orbit 86 start	2021-06-10 08:31:03	2375.85639	826849
Orbit 86 end	2021-06-24 05:11:02	2389.71750	836829

[a] TJD = TESS JD = JD - 2,457,000.0

The spacecraft was pointing at RA (J2000): 242.1981°; Dec (J2000): −76.3969°; Roll: 161.5986°. See the TESS project Sector 39 observation page[3] for the coordinates of the spacecraft pointing and center field-of-view of each camera. Fields-of-view for each camera can be found at the TESS Guest Investigator Office observations status page.[4] The detailed target list for both 2-minute and 20-second data, as well as the Guest Investigator target lists, can be found at the Sector 39 observation page and the observations status page.

1.1 Update to the TIC

The TESS Input Catalog (TIC) was updated to v8.2 for data processing in Sector 39. The TIC v8.2 update identifies newly discovered `ARTIFACT` and `DUPLICATE` sources that were not flagged in the v8.0/8.1 revisions of the TIC. TIC stars labeled `ARTIFACT` are not stars, but rather non-astrophysical objects caused by diffraction spikes, image ghosting, bleed trails, or other similar phenomena. A TIC star labeled `DUPLICATE` is effectively an exact copy of of another TIC star: the other TIC star is called the "parent" and is considered the 'official' entry for that star. The detailed description of these labels can be found in the MAST archives.

The Sector 39 targets were selected using TIC v8.1 and processed with TIC v8.2. As a result, several dozen targets identified in TIC v8.2 as `DUPLICATE` or `ARTIFACT` were processed. For newly flagged `ARTIFACT` sources, target pixel files are produced, but no light curves or DV products are produced. For `DUPLICATE` sources, if the "parent" TIC ID was not also a target, target pixel files, light curves, and DV products are produced using the `DUPLICATE` TIC ID in the file name. If the "parent" was also observed, the full set of target pixel files, light curves, and DV products are produced for the parent, but only target pixel files are produced for the `DUPLICATE`. These target pixel files do not include a background correction.

In total, there were 10 `ARTIFACT` and 74 `DUPLICATE` sources selected in Sector 39 with no light curves or DV products. There are 35 `DUPLICATE` sources with light curves and DV

[3] https://tess.mit.edu/observations/sector-39

[4] https://heasarc.gsfc.nasa.gov/docs/tess/status.html

products (where applicable). A table of the TIC IDs without light curves, their flags, and parent star TIC IDs (for which light curves exist) is given in Appendix A as well as in a supplemental file[5].

1.2 Notes on Individual Targets

There are no clipped apertures for the 20-second targets and their data products and all have light curves.

For the 2-minute cadence data, eight bright stars (Tmag $\lesssim 1.8$) with large pixel stamps were not processed in the photometric pipeline. Target pixel files with original and calibrated pixel data are provided, but no light curves were produced. Note that the TPF files do not include a background correction for stars without light curves. The affected TIC IDs are 364216056, 38877693, 262834160, 191437754, 238196512, 325635393, 17158018, and 171207618.

Two target stars (300015238, 217157392) are blended with comparably bright stars—the contaminating flux for these objects is very large, and the resulting photometry for such targets is expected to be unreliable.

One star (247258119) is close enough to the bleed trail from a brighter star that the photometry is likely unreliable.

One target star (340411626) are closely blended with brighter neighbors. In this case, the assigned aperture is disjoint and the resulting photometry is unreliable.

One target (384196595) has a pixel stamp that does not fully capture the bleed trails.

1.3 Spacecraft Pointing and Momentum dumps

Both Cameras 1 and 4 were used for guiding in orbits 85 and 86 of Sector 39. A single momentum dump was performed halfway through each orbit. Figure 1 summarizes the pointing performance over the course of the sector based on Fine Pointing telemetry.

1.4 Scattered Light

Figure 2 shows the median value of the background estimate for all targets on a given CCD as a function of time. Figure 3 shows the angle between each camera's boresight and the Earth or Moon—this figure can be used to identify periods affected by scattered light and the relative contributions of the Earth and Moon to the image backgrounds.

In Sector 39, there is scattered light for most of both orbits.

2 Data Anomaly Flags

See the SDPDD (§9) for a list of data quality flags and the associated binary values used for TESS data, and the TESS Instrument Handbook for a more detailed description of each flag.

[5] https://archive.stsci.edu/missions/tess/catalogs/targetinfo/tess_sector_39_drn56_artdupnolc_v01.txt

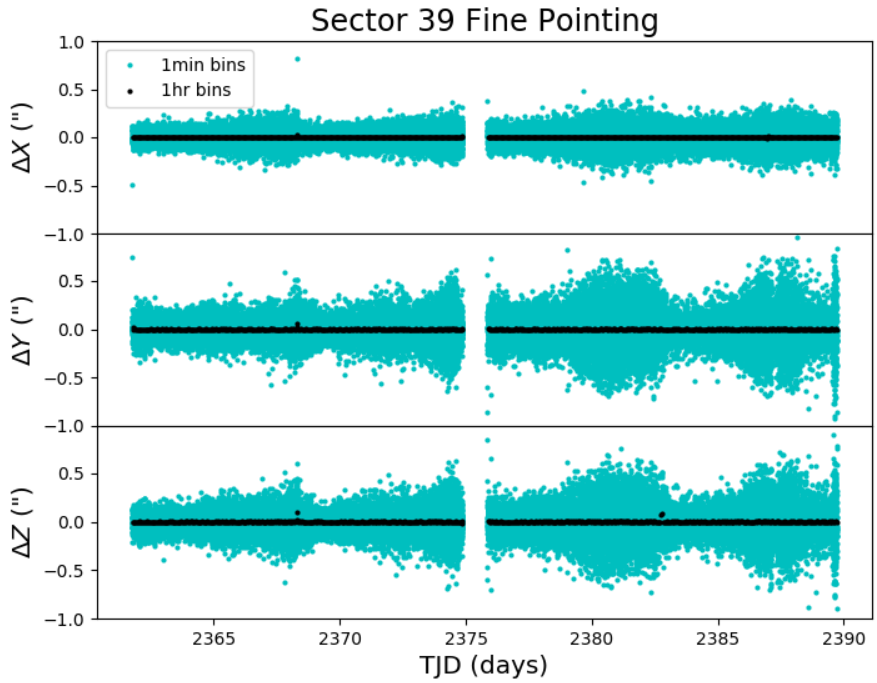

Figure 1: The delta-quaternions from each camera have been converted to spacecraft frame, binned to 1 minute and 1 hour, and averaged across cameras. Long-term trends (such as those caused by differential velocity aberration) have also been removed. The ΔX/ΔY directions represent offsets along the the detectors' rows/columns, while the ΔZ direction represents spacecraft roll.

The following flags were not used in Sector 39: bits 1, 2, and 9 (Attitude Tweak, Safe Mode, and Discontinuity).

Cadences marked with bits 3, 4, 6, and 12 (Coarse Point, Earth Point, Reaction Wheel Desaturation Event, and Straylight) were marked based on spacecraft telemetry.

Cadences marked with bit 5 and 10 (Argabrightening Events and Impulsive Outlier) were identified by the SPOC pipeline. Bit 5 marks a sudden change in the background measurements. In practice, bit 5 flags are caused by rapidly changing glints and unstable pointing at times near momentum dumps. Bit 10 marks an outlier identified by PDC and omitted from the cotrending procedure.

The 20-second data mode includes cadences marked with bit 7 and 11 (Cosmic Ray in Optimal Aperture and Cosmic Ray in Collateral Pixel). These flags indicate cadences affected by cosmic rays that are removed by the pipeline, and can be found in both the TPF and LC files. The data provided in the archive products are corrected for cosmic rays, and a `FITS` table extension in the TPF and Collateral Pixel File details the cosmic rays identified and removed by the pipeline at the pixel level.

Cadences marked with bit 8 (Manual Exclude) are ignored by PDC, TPS, and DV for cotrending and transit searches. In Sector 39, these cadences were identified using spacecraft telemetry from the fine pointing system. All cadences with pointing excursions >7 arcsec (0.3 pixel) were flagged for manual exclude. Figure 4 also shows an assessment of the performance

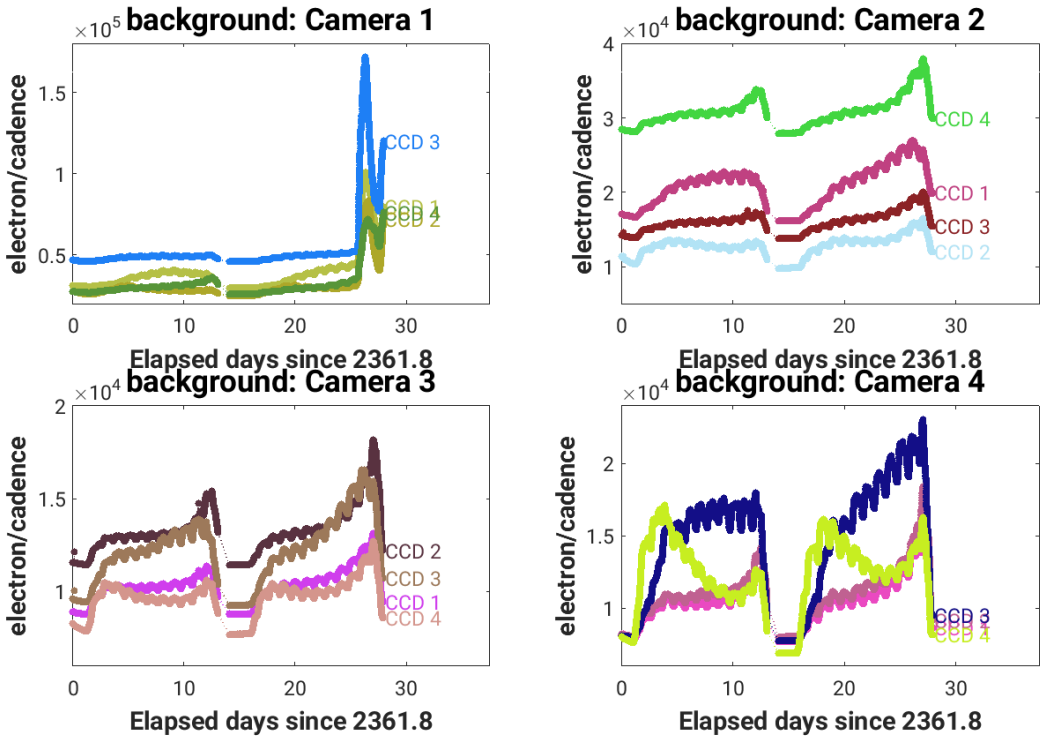

Figure 2: Median background flux across all targets on a given CCD in each camera. The changes are caused by variations in the orientation and distance of the Earth and Moon.

of the cotrending based on the final set of manual excludes.

The predicted stray light flag (bit 12, value 2048) is marked in the FFIs and flags times when the Earth/Moon are near the camera FOVs and may interfere with guiding or saturate the detectors. We strongly recommend that users inspect the FFI data before removing images marked with bit 12, because this bit is set based on predictions from mission planning and is known to be conservative with respect to the quality of data usable for analysis.

The predicted stray light flag (bit 12) is disabled for the 2-minute and 20-second data products. The scattered light exclude flag (bit 13, value 4096) identifies cadences at which individual targets are affected by scattered light

If the Earth/Moon interference is strong enough to saturate the detector, all targets on a CCD slice will be affected and the data are unusable. Cadences with bad calibrations due to saturation are now explicitly marked with bit 15 (value 16384, "Bad Calibration Exclude"). For some cadences, the majority of targets on a CCD may be flagged for scattered light and not enough valid data remains to derive cotrending basis vectors in PDC. No systematic error correction can be applied at these times. This situation is identified by bit 16 (value 32768, "Insufficient Targets for Error Correction Exclude").

FFIs were only marked with bits 3, 6, 8, 12, and 15 (Coarse Point, Reaction Wheel Desaturation Events, Manual Exclude, Straylight, and Bad Calibration Exclude). Only one FFI is affected by each momentum dump. There are no WCS coordinates for FFIs that coincide with momentum dumps.

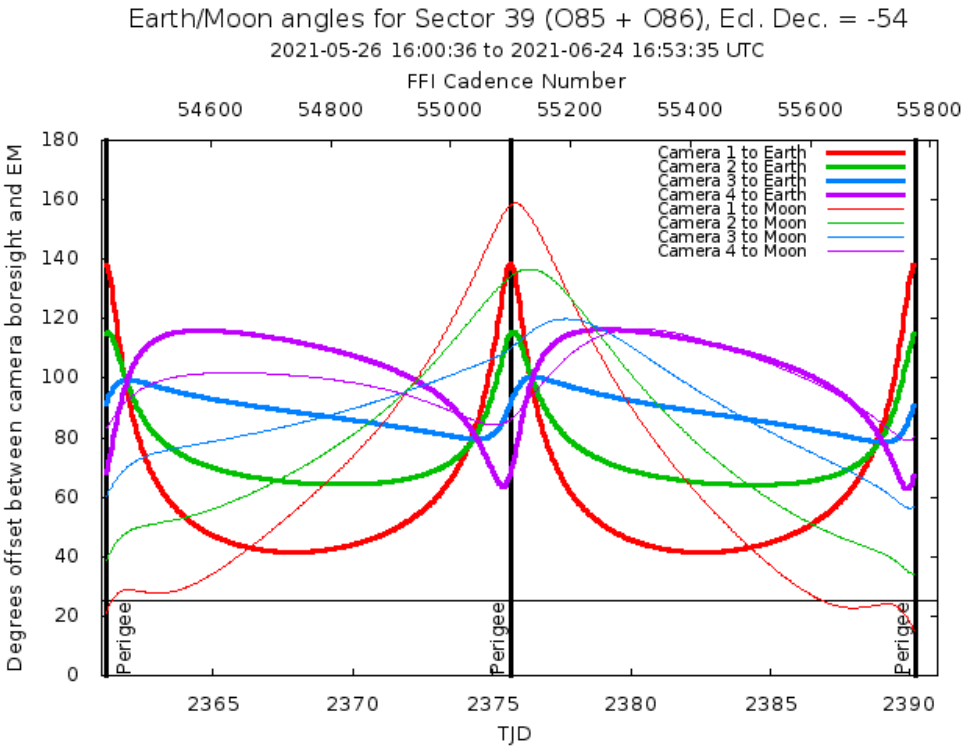

Figure 3: Angle between the four camera boresights and the Earth/Moon as a function of time. When the Earth is within $\sim 25°$ of a camera's boresight, transiting planet searches may be compromised by high levels of scattered light. At larger angles, up to $\sim 35°$, scattered light patterns and complicated structures may be visible. At yet larger angles, low level patchy features may be visible. Scattered light from the Moon is generally only noticeable below $\sim 35°$. This figure can be used to identify periods affected by scattered light and the relative contributions of the Earth and Moon to the background. However, the background intensity and locations of scattered light features depend on additional factors, such as the Earth/Moon azimuth and distance from the spacecraft.

3 Anomalous Effects

3.1 Smear Correction Issues

The following columns were impacted by bright stars in the science frame, and/or upper buffer rows, and/or lower science frame rows, which bleed into the upper serial register resulting in an overestimated smear correction. The smear column 2083 for camera 3 and ccd 4 was measured to be anomalously bright relative to the science data column without a readily apparent stellar source of contamination.

- Camera 2, Ccd 3, Column 1033 - Star Eta Pavonis
- Camera 2, Ccd 4, Column 546 - Star Delta Trianguli Australis
- Camera 3, Ccd 4, Column 264 - Star CPD-86 250
- Camera 3, Ccd 4, Column 2083 - Unknown source

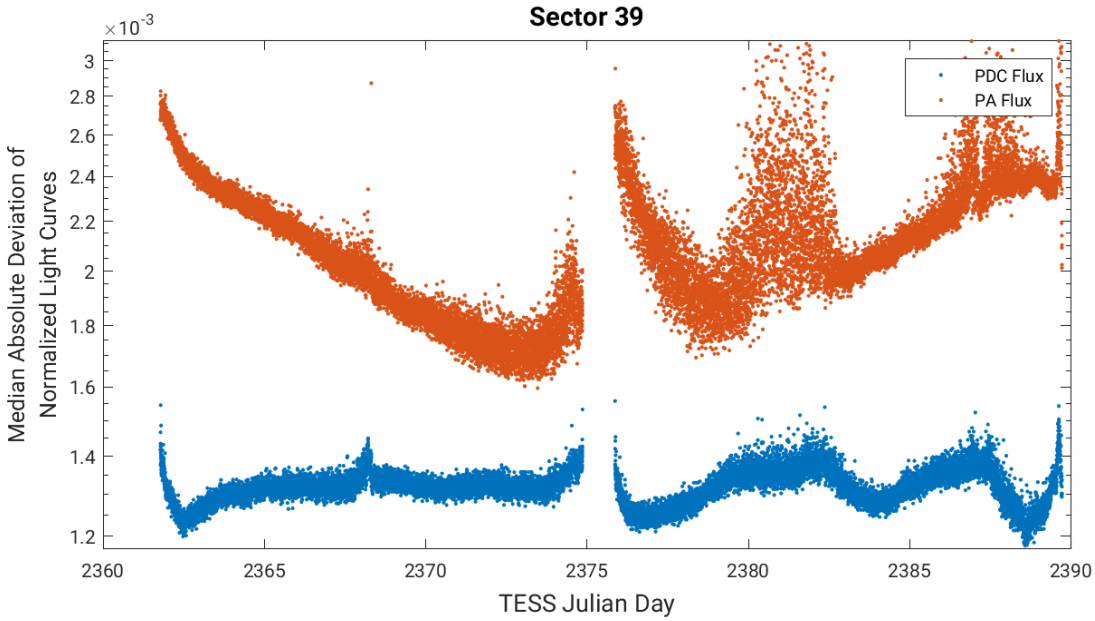

Figure 4: Median absolute deviation (MAD) for the two-minute cadence data from Sector 39, showing the performance of the cotrending after identifying Manual Exclude data quality flags. The MAD is calculated in each cadence across stars with flux variations less than 1% for both the PA (red) and PDC (blue) light curves, where each light curve is normalized by its median flux value. The scatter in the PA light curves is much higher than that for the PDC light curves, and the outliers in the PA light curves are largely absent from the PDC light curves due to the use of the anomaly flags.

- Camera 4, Ccd 1, Column 517 - Star HD 28398
- Camera 4, Ccd 2, Column 513 - Star HD 46819
- Camera 4, Ccd 3, Column 823 - Star HD 55546

3.2 Fireflies and Fireworks

Table 2 lists all firefly and fireworks events for Sector 39. These phenomena are small, spatially extended, comet-like features in the images—created by sunlit particles in the camera FOV—that may appear one or two at a time (fireflies) or in large groups (fireworks). See the TESS Instrument Handbook for a more complete description.

4 Pipeline Performance and Results

4.1 Light Curves and Photometric Precision

Figure 5 gives the PDC goodness metrics for the two-minute cadence data, with residual correlation goodness and introduced noise goodness shown on a scale between 0 (bad) and 1 (good). The performance of PDC is very good and generally uniform over most of the field

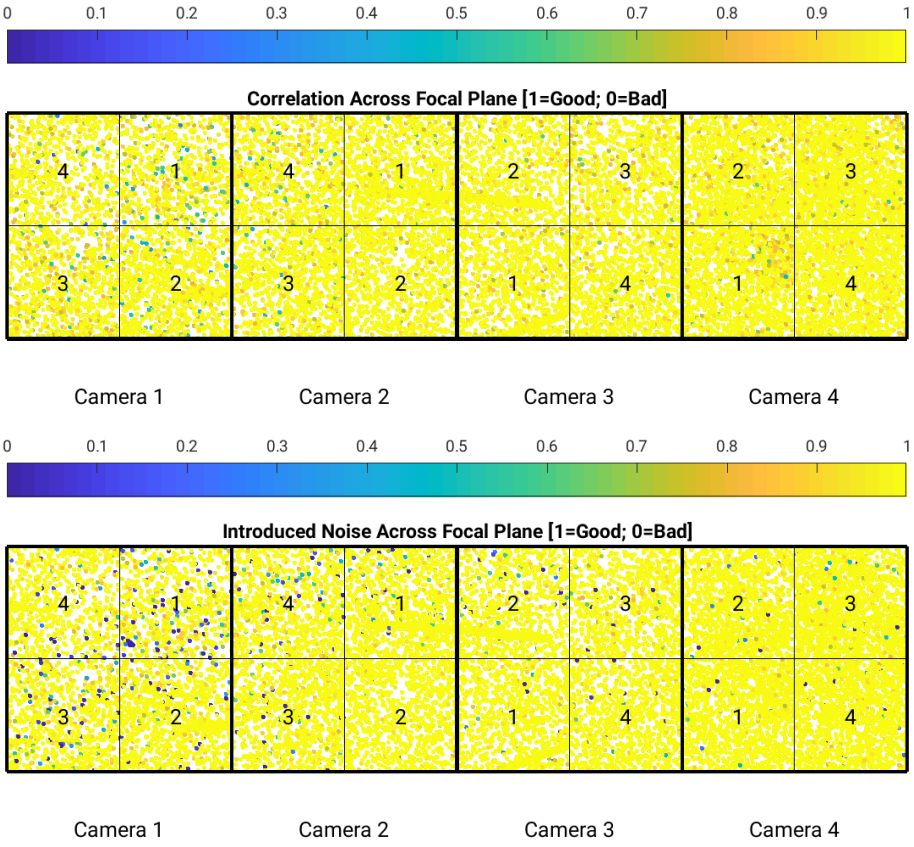

Figure 5: PDC residual correlation goodness metric (top panel) and PDC introduced noise goodness metric (bottom panel) for the two-minute cadence data. The metric values are shown on a focal plane map indicating the camera and CCD location of each target. The correlation goodness metric is calibrated such that a value greater than 0.8 means there is less than 10% mean absolute correlation between the target under study and all other targets on the CCD. The introduced noise metric is calibrated such that a value greater than 0.8 means the power in broad-band introduced noise is below the level of uncertainties in the flux values.

of view. Figure 6 shows the achieved Combined Differential Photometric Precision (CDPP) at 1-hour timescales for all two-minute targets.

4.2 Transit Search and Data Validation

In Sector 39, the two-minute light curves of 19908 targets were subjected to the transit search in TPS. Of these, Threshold Crossing Events (TCEs) at the 7.1 σ level were generated for 1419 targets.

We employed an iterative method when conducting the Sector 39 transit search. The top panel of Figure 7 shows the number of TCEs at a given cadence that exhibit a transit signal from an initial run of TPS. The 3-σ peaks were used to define de-emphasis weights for a second run of TPS, the results of which are shown in the bottom panel of Figure 7. The final set of TCEs and the results reported here are based on the second run of TPS. The values of the adopted de-emphasis weights are provided in the DV timeseries data products

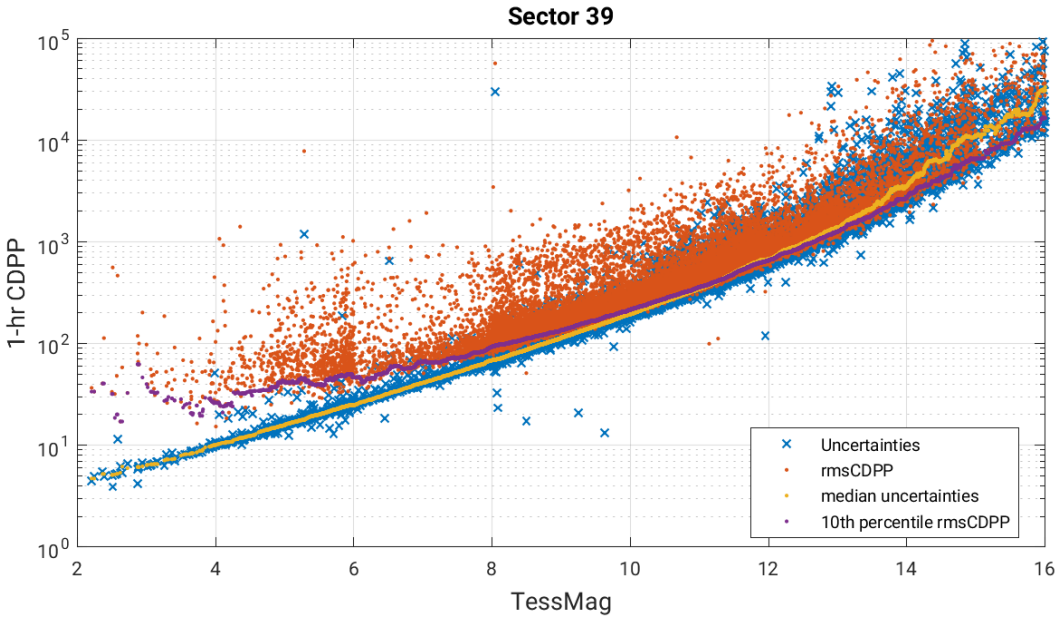

Figure 6: 1-hour CDPP. The red points are the RMS CDPP measurements for the 19908 light curves from Sector 39 plotted as a function of TESS magnitude. The blue x's are the uncertainties, scaled to 1-hour timescale. The purple curve is a moving 10th percentile of the RMS CDPP measurements, and the gold curve is a moving median of the 1-hr uncertainties.

for targets with TCEs.

The top panel of Figure 8 shows the distribution of orbital periods for the final set of TCEs found in Sector 39. The vertical histogram in the right panel of Figure 8 shows the distribution of transit depths derived from limb-darkened transiting planet model fits for TCEs. The model transit depths range down to the order of 100 ppm, but the bulk of the transit depths are considerably larger.

A search for additional TCEs in potential multiple planet systems was conducted in DV through calls to TPS. A total of 2014 TCEs were ultimately identified in the SPOC pipeline on 1419 unique target stars. Table 3 provides a breakdown of the number of TCEs by target. Note that targets with large numbers of TCEs are likely to include false positives.

Note that for those targets observed in both Year 1 and Year 3, Year 3 processing was

Table 2: Sector Fireflies and Fireworks

FFI Start	FFI End	Cameras	Description
2021147072904	2021147073904	2	Firefly
2021147094904	2021147095904	2,3,4	Fireflies
2021158133903	2021158135903	1,2,3	Fireworks
2021160002903	2021160003903	2	Firefly
2021161141903	2021161142903	2	Firefly
2021161143903	2021161144903	2	Firefly

done using TIC 8.1 while TIC 7 was used for Year 1 processing; this may result in differences in results for certain targets. Differences for some crowded and/or dim targets may also result from the background correction algorithm update introduced in Sector 27 (see DRN38).

Table 3: Sector 39 TCE Numbers

Number of TCEs	Number of Targets	Total TCEs
1	957	957
2	360	720
3	79	237
4	16	64
5	6	30
6	1	6
–	1419	2014

Appendix A

The following table lists TIC IDs of Sector 39 targets that were flagged as `ARTIFACT` or `DUPLICATE` in v8.2 of the TIC. For all `DUPLICATE` sources, the parent star was observed and data products for the parent should be used. For the tabulated targets, target pixel files (without background subtraction) are available, but light curves and DV products are not available.

Table 4: Sector 39 `ARTIFACT` and `DUPLICATE` Sources Without Light Curves

TIC ID	Disposition	Parent TIC ID
9252615	ARTIFACT	None
272429505	ARTIFACT	None
274590112	ARTIFACT	None
277025286	ARTIFACT	None
301300709	ARTIFACT	None
307435285	ARTIFACT	None
350345734	ARTIFACT	None
382099937	ARTIFACT	None
403404205	ARTIFACT	None
426266384	ARTIFACT	None
630705685	DUPLICATE	273788401
630710729	DUPLICATE	261657047
649985020	DUPLICATE	410355565
650140833	DUPLICATE	238227682
684767046	DUPLICATE	55745232
684996650	DUPLICATE	293218107
724107963	DUPLICATE	392013575

730543928	DUPLICATE	373916957
733027940	DUPLICATE	149248196
734548585	DUPLICATE	350744311
737163462	DUPLICATE	150357613
737165368	DUPLICATE	150391195
765325999	DUPLICATE	349376367
765419969	DUPLICATE	167552090
765444982	DUPLICATE	349154302
765561912	DUPLICATE	349683698
766018849	DUPLICATE	167602316
766092864	DUPLICATE	279511712
804804891	DUPLICATE	272429506
804862160	DUPLICATE	452467437
842776931	DUPLICATE	388238508
843245247	DUPLICATE	452604247
843283157	DUPLICATE	452591868
903831225	DUPLICATE	369864932
904264399	DUPLICATE	395011859
954686803	DUPLICATE	357468855
955210093	DUPLICATE	360946710
1003457120	DUPLICATE	418616237
1003843902	DUPLICATE	418385999
1005005237	DUPLICATE	396693868
1104778329	DUPLICATE	402726344
1109703154	DUPLICATE	263493131
1112343883	DUPLICATE	424717049
1121747911	DUPLICATE	258708320
1121965222	DUPLICATE	259424304
1139106989	DUPLICATE	72254026
1157913335	DUPLICATE	255350860
1206529115	DUPLICATE	363378214
1247277024	DUPLICATE	69883377
1248002609	DUPLICATE	374648382
1251579395	DUPLICATE	211154793
1255376980	DUPLICATE	95789856
1309555084	DUPLICATE	384663180
1309921218	DUPLICATE	310662196
1310202413	DUPLICATE	310425416
1310815606	DUPLICATE	301300706
1310863552	DUPLICATE	381234046
1311852400	DUPLICATE	255831179
1312885302	DUPLICATE	447179213
1338933213	DUPLICATE	236083927
1402530793	DUPLICATE	112584039
1413140927	DUPLICATE	112652873

1508648123	DUPLICATE	276673568
1508682013	DUPLICATE	276565213
1508739555	DUPLICATE	384800098
1508852349	DUPLICATE	311961315
1512223285	DUPLICATE	76313563
1514604798	DUPLICATE	421289676
1523651762	DUPLICATE	218094872
1547248536	DUPLICATE	198460187
1589107510	DUPLICATE	196491062
1688192735	DUPLICATE	277034621
1688409799	DUPLICATE	343757899
1688411360	DUPLICATE	343600323
1689034476	DUPLICATE	304342496
1689329798	DUPLICATE	365328267
1689524588	DUPLICATE	411923951
1689665121	DUPLICATE	345052391
1690191343	DUPLICATE	118728604
1691862065	DUPLICATE	381720313
1698462127	DUPLICATE	86140963
1922049647	DUPLICATE	257577230
2025810344	DUPLICATE	325395450
2054449464	DUPLICATE	327854581

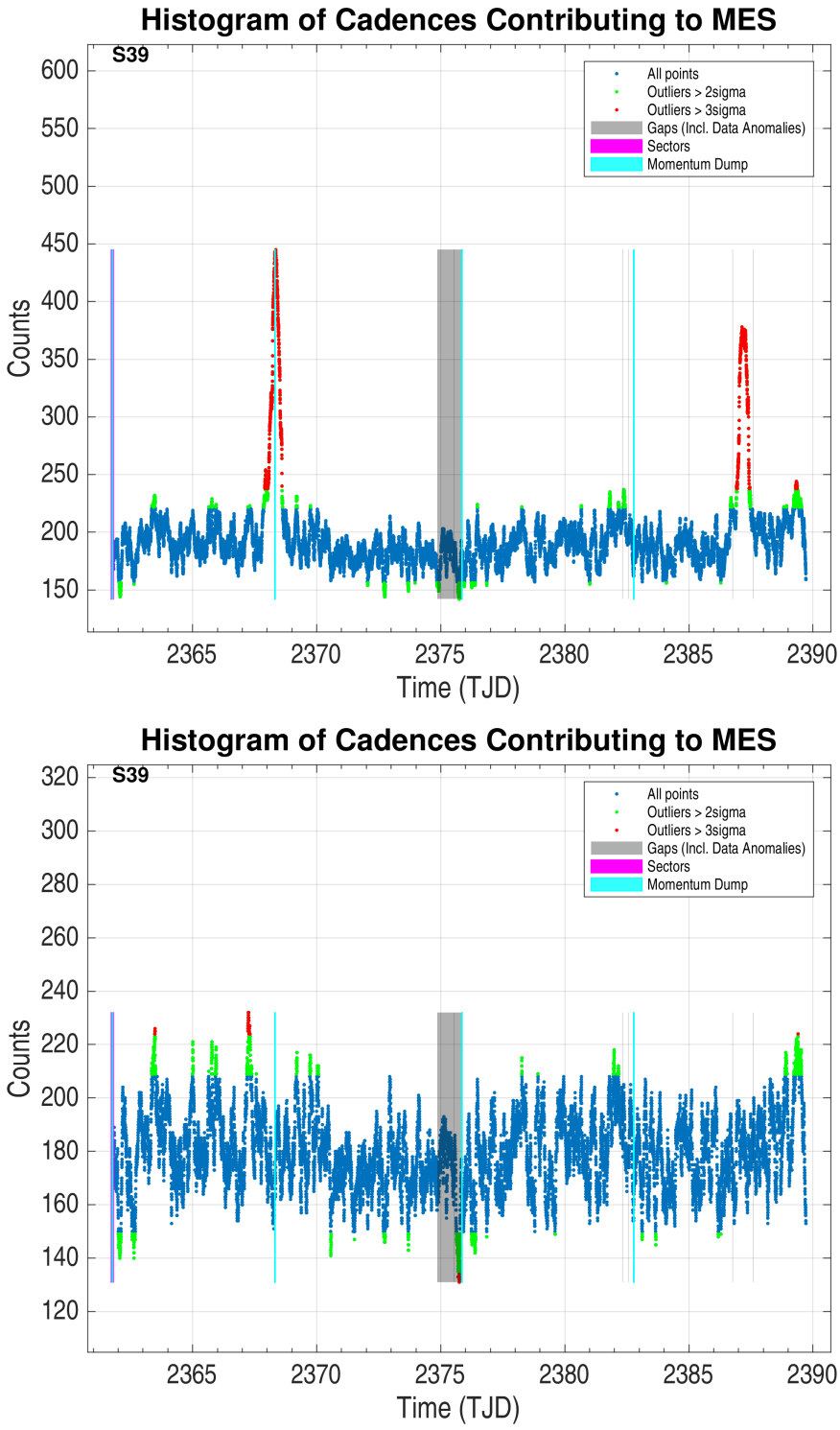

Figure 7: Top panel: Number of TCEs at a given cadence exhibiting a transit signal, based on an initial run of TPS. Any isolated peaks are caused by single events that result in spurious TCEs. These peaks were used to define de-emphasis weights that suppress problematic epochs for the transit detection statistics in a second iteration of TPS. Bottom panel: Results from the second run of TPS.

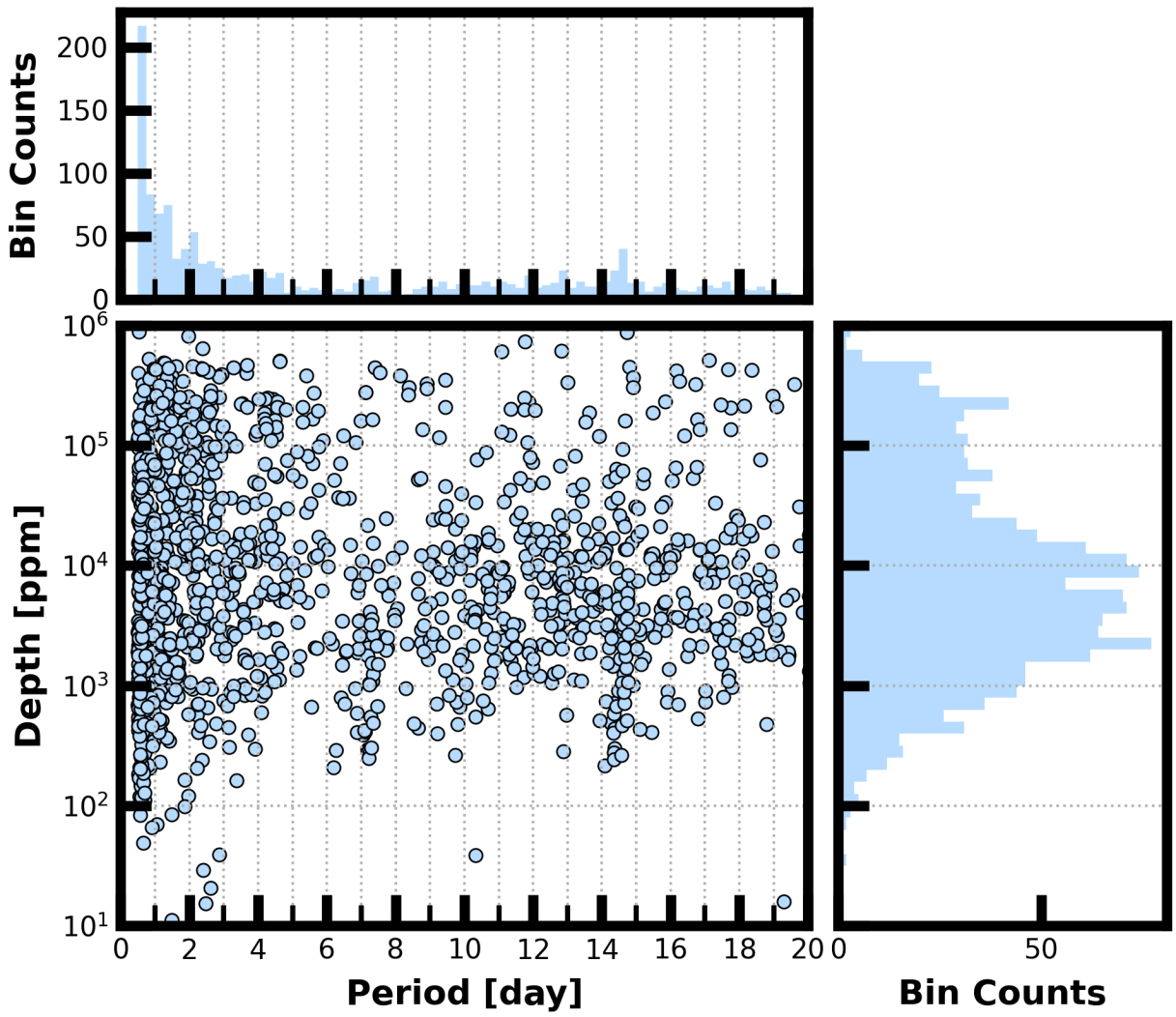

Figure 8: Lower Left Panel: Transit depth as a function of orbital period for the 2014 TCEs identified for the Sector 39 search. For enhanced visibility of long period detections, TCEs with orbital period <0.5 days are not shown. Reported depth comes from the DV limb-darkened transit fit depth when available, and the DV trapezoid model fit depth when not available. Top Panel: Orbital period distribution of the TCEs shown in the lower left panel. Right Panel: Transit depth distribution for the TCEs shown in the lower left panel.

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Acronyms and Abbreviation List

BTJD Barycentric-corrected TESS Julian Date

CAL Calibration Pipeline Module

CBV Cotrending Basis Vector

CCD Charge Coupled Device

CDPP Combined Differential Photometric Precision

COA Compute Optimal Aperture Pipeline Module

CSCI Computer Software Configuration Item

CTE Charge Transfer Efficiency

Dec Declination

DR Data Release

DV Data Validation Pipeline Module

DVA Differential Velocity Aberration

FFI Full Frame Image

FIN FFI Index Number

FITS Flexible Image Transport System

FOV Field of View

FPG Focal Plane Geometry model

KDPH Kepler Data Processing Handbook

KIH Kepler Instrument Handbook

KOI Kepler Object of Interest

MAD Median Absolute Deviation

MAP Maximum A Posteriori

MAST Mikulski Archive for Space Telescopes

MES Multiple Event Statistic

NAS NASA Advanced Supercomputing Division

PA Photometric Analysis Pipeline Module

PDC Pre-Search Data Conditioning Pipeline Module

PDC-MAP Pre-Search Data Conditioning Maximum A Posteriori algorithm

PDC-msMAP Pre-Search Data Conditioning Multiscale Maximum A Posteriori algorithm

PDF Portable Document Format

POC Payload Operations Center

POU Propagation of Uncertainties

ppm Parts-per-million

PRF Pixel Response Function

RA Right Ascension

RMS Root Mean Square

SAP Simple Aperture Photometry

SDPDD Science Data Products Description Document

SNR Signal-to-Noise Ratio

SPOC Science Processing Operations Center

SVD Singular Value Decomposition

TCE Threshold Crossing Event

TESS Transiting Exoplanet Survey Satellite

TIC TESS Input Catalog

TIH TESS Instrument Handbook

TJD TESS Julian Date

TOI TESS Object of Interest

TPS Transiting Planet Search Pipeline Module

UTC Coordinated Universal Time

WCS World Coordinate System

XML Extensible Markup Language